STUDIES OF MARINE EPIPHYTIC ALGAE, CALVI, CORSICA. III. VARIATIONS IN THE POPULATIONS OF EPIPHYTIC BANGIOPHYCEAE

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ABSTRACT - Variations in the populations of Bangiophyceae (Rhodophyta) epiphytic on *Cladophora prolifera* and *Stypocaulon scoparium* were monitored qualitatively and quantitatively for two years (1981/82 and 1987/88) in nine stations with constrasting water quality in the area of Calvi (Corsica). The development of *Chroodactylon ornatum* was temperature dependent and showed its maximum density during the summer. The development of the other Bangiophyceae (*Erythrocladia irregularis, Erythrotrichia carnea, Goniotrichum alsidii, G. cornu-cervi*) was correlated to the water quality in that their density increased towards the sewage discharge near to the town of Calvi. A general increase in epiphytism by Bangiophyceae between 1981 and 1988 seems to indicate an increased degree of eutrophication in the bay of Calvi.

RÉSUMÉ - Les variations des populations de Bangiophycées (Rhodophyta) épiphytiques sur *Cladophora prolifera* et *Stypocaulon scoparium* ont été étudiées quantitativement et qualitativement pendant deux ans (1981/1982 et 1987/88) dans neuf stations près de Calvi (Corse). Le développement de *Chroodactylon ornatum* dépendait de la température et l'algue montrait une présence maximale en été. Le développement des autres Bangiophycées (*Erythrocladia irregularis, Erythrotrichia carnea, Goniotrichum alsidii, G. cornu-cervi*) était lié à la qualité de l'eau et leur densité diminuait à partir de l'égout près de la ville de Calvi. Une augmentation générale de l'épiphytisme par les Bangiophycées entre 1981 et 1988 semble indiquer un degré d'eutrophisation accrue dans la baie de Calvi.

KEY WORDS: Bangiophyceae, eutrophication, bioindicator, Corsica.

INTRODUCTION

Little is known about the ecology of marine microscopic Bangiophyceae (Rhodophyta). However, under certain circumstances they are so abundant, that their role in benthic ecosystems must be far from negligible. Belsher (1974) showed that under certain conditions, Bangiophyceae (especially the genus *Erythrotrichia* Areschoug) can constitute up to 20% of the coverage formed by benthic algae. He furthermore revealed an increasing importance of Bangiophyceae when approaching a seawage discharge, indicating that these microscopic algae could be used as bioindicators for

pollution. The present contribution reports changes in the populations of Bangiophyceae growing on the phorophytes *Stypocaulon scoparium* (L.) Kütz. [*Halopteris scoparia* (L.) Sauv.] and *Cladophora prolifera* (Roth) Kütz. in the region of Calvi (Corsica) during two yearly cycles (1981/1982 and 1987/88). The demography and ecology of the different taxa of epiphytic Bangiophyceae is described for the 1987/88 study period.

MATERIALS AND METHODS

Sampling sites

The specimens of the phorophytes were collected by SCUBA diving in 1981/82 (July, September, December, March) and in 1987/88 (September, December, March, July). The algae were collected at a depth of 5 m (*Stypocaulon*) and of 1.5 m (*Cladophora*) in the following stations in the vicinity of Calvi (Fig. 1): "Pointe Revellata" (LP): ■ wave exposed north-east facing station. "Stareso" (ST): a small harbour belonging to the field station of the University of Liège, south-east facing, with maximum depth of 10 m and which can be very turbulent during the winter. Since occupation of the station is minimal at this time of the year, sewage from the station, which discharges into the harbour, has a limited impact at this time. In summer there is

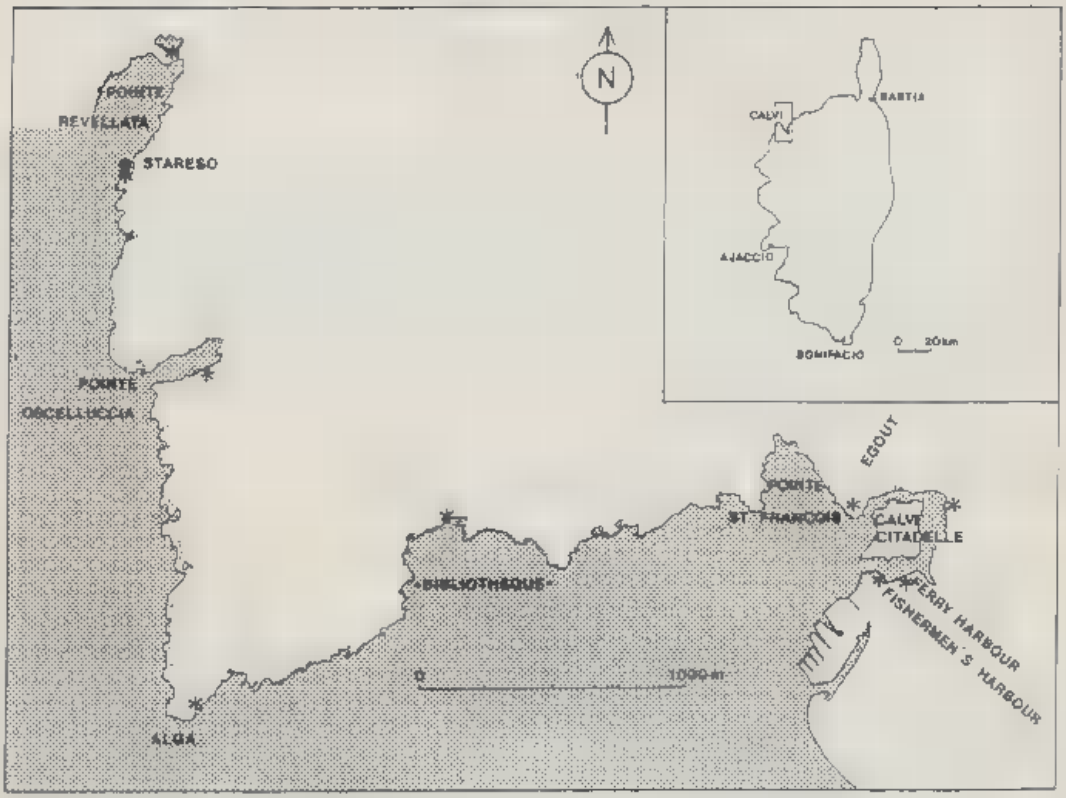

Fig. 1 - Locations of the sampling stations (*) in the study area (vicinity of Calvi).

some pollution (domestic and laboratory effluents) due to limited water movement and maximal occupation of the station. In the 1981/82 study period, epiphytic Bangiophyceae were not sampled on *Stypocaulon scoparium* in the harbour of Stareso. "Pointe Oscelluccia" (OS): protected, east facing station, a small seasonal stream discharges near the station. "Alga" (AL): a calm and thermophilic, north-west facing station, a small, seasonal stream discharges near the station. The thermophilic character of the station is indicated by the presence of *Anadyomene stellata* (Wulfen) C. Ag. and *Digenea simplex* (Wulfen) C. Ag. "Bibliothèque" (BI: a wave exposed, north-east facing station. "Egout" (EG): a north-west facing, wave exposed station; a discharge area for the sewage of the town of Calvi with about 3,000 inhabitants. The population can increase to 25,000 in summer causing great seasonal variations in the sewage discharge. "Citadelle" (CI): a wave exposed, north-west facing station. "Ferry harbour" (PCO): a well-protected harbour with a wide entry that guarantees an efficient mixing with the water from the open sea. No sewer directly discharges into this harbour, which probably only suffers minor pollution arriving from the adjacent Fishermen's harbour. Mud, placed in suspension by the traffic of large boats, covers the algae. The maximum depths is 12 m. "Fishermen's harbour" (PPE): a small, calm, 2 m deep harbour. Algae are rather scarce. It receives occasional discharges from a minor city sewer, and some pollution diffuses into it from the adjacent yatch harbour which in summer is densely populated.

Phosphorus concentrations are similar in all the stations around the bay in both spring and winter. In summer however, two different situations are observed: on the one hand the "Egout" with a continuous, high nutrient input through the sewage discharge due to the increased tourist population in the town of Calvi and on the other hand the other stations around the bay with phosphorus concentrations below the limits of detection.

Reactive phosphorus was determined according to Strickland & Parsons (1965) (limit of detection: 0.2 µg-P l^{-1}) in samples taken at a depth of 1 m in 1981 and 1982. In December, phosphorus concentrations vary in the open sea stations between 4.5 and 8.0 µg-P l^{-1}, with a maximum of 13.8 µg-P l^{-1} at the "Egout". In March and in June, the concentrations were below the limit of detection, except at the "Egout", where a maximum concentration of 47.4 µg-P l^{-1} was measured in June. In the harbours, the concentrations varied in December between 6.0 (Stareso) and 7.6 µg-P l^{-1} (Ferry harbour); in March and in June, they were below 1.0 µg-Pl^{-1}.

To monitor the sewage contamination, coliform counts were made at a depth of 1 m in May and June 1982, in September 1987, and in March 1988. This was done in triplicate by the standard total coliform membrane filter colimetry (Greenberg *et al.*, 1980) with the Tergitol-7-agar medium (Merck). In spring, only 10 to 20 colonies l^{-1} are recorded in the open sea stations, except at the "Egout" where up to 300 colonies l^{-1} are counted. In summer, colony numbers varied between 10 and 50 l^{-1} at the non polluted stations "Pointe", "Oscelluccia" and "Alga". The maximum colony number was reached at the "Egout" with over 10.000 colonies 1000 l^{-1}. At the neighbouring stations of the "Egout" ("Bibliothèque", "Citadelle"") up to 400 colonies l^{-1} were counted. In Stareso only 10 to 20 colonies l^{-1} and zero to three at the Ferry harbour were counted in May. In June the colony numbers increased to 550-900 l^{-1} at Stareso, where occupation had risen, but remained only five to twelve in the Ferry harbour. The

coliform countings showed that the "Egout" and the surrounding stations "Bibliothèque" and "Citadelle" were most influenced by the sewage discharge, especially in summer. A variable, slight contamination, depending on the occupation of the Biological Station, was also observed in Stareso. These two parameters (coliform contamination and phosphorus concentration) clearly indicate that the "Egout" and the surrounding stations are the most polluted and those with the highest nutrient concentrations; this contrast is especially evident during the summer period.

Choice of phorophytes

The phorophytes studied were the green alga *Cladophora prolifera*, which is a pollution-tolerant species (Van den Hoek, 1963; Schramm & Booth, 1981), present in the harbours, but absent or only rarely encountered in the open water stations and *Stypocaulon scoparium*, a widespread species in the Calvi area in open waters and which is also present in the harbour of Stareso.

Methods of observation

The total number of individuals of Bangiophyceae was counted by using the sampling units as defined by Wilmotte *et al.* (1988), i.e. the upper surface of the first 6 mm (starting from the apex) of 45 shoots for *Cladophora* (average surface 1.2 mm^2) and the upper surface of the first millimeter of the apex of 20 secondary ramifications for *Stypocaulon* (average surface 0.1 mm^2). Counts were made using a 40 x objective on fresh material or on material preserved in 4% formaldehyde in sea water.

Taxonomic categories

In the Calvi area, five genera of epiphytic Bangiophyceae, i.e. *Bangia* Lyngb., *Chroodactylon* Hansg., *Erythrocladia* Rosenv., *Erythrotrichia* Areschoug and *Stylonema* Reinsch are encountered. *Bangia* is very rare and was not recorded during our study. The genus *Chroodactylon* is represented by one species, *C. ornatum* (C. Ag.) Drew et Ross, and the genus *Stylonema* by two species, *S. alsidii* (Zanard.) Drew and *S. cornu-cervi* Reinsch. Whereas these taxa are well defined, this is not the case for the genera *Erythrocladia* and *Erythrotrichia* (e.g. Dangeard, 1932, 1968, 1969; Heerebout, 1968; Nichols & Lissant, 1967; Kornmann, 1984, 1989; Kornmann & Sahling, 1985). Given the intermediates observed in nature and the variations recorded in culture, it is considered that all the *Erythrotrichia* collected are better referred to a single variable species, *E. carnea* (Dillw.) J. Ag., as done by Heerebout (1968), rather than to several species following Dangeard. It is interesting that high light intensities and high nutrient levels seem to promote a pluriseriate condition (Lamproye & Demoulin, 1985). For *Erythrocladia* we follow again the species concept of Heerebout (1968) and retain a single species *E. irregularis* Rosenv.

RESULTS

Chroodactylon ornatum (C. Ag.) Drew et Ross (Fig. 2)

C. ornatum was the less common epiphytic Bangiophyceae in the Calvi area. The species, almost absent during winter and spring, was more abundant in summer when it could constitute up to 100% of the epiphytic Bangiophyceae (e.g. "Alga", July 1988). On *Stypocaulon*, in the open ocean stations, the species had its optimal development at "Oscelluccia" and "Alga", two protected stations in the centre of the bay. The highest density recorded was 7.4 ind. mm^{-2} at "Alga" in September. This taxon seemed not to be favoured in the stations with the highest nutrient concentrations ("Egout" and neighbouring stations). On *Cladophora* in Stareso and in the Ferry harbour it was present at very low density and only in the summer; in the Fishremen's harbour it was not observed.

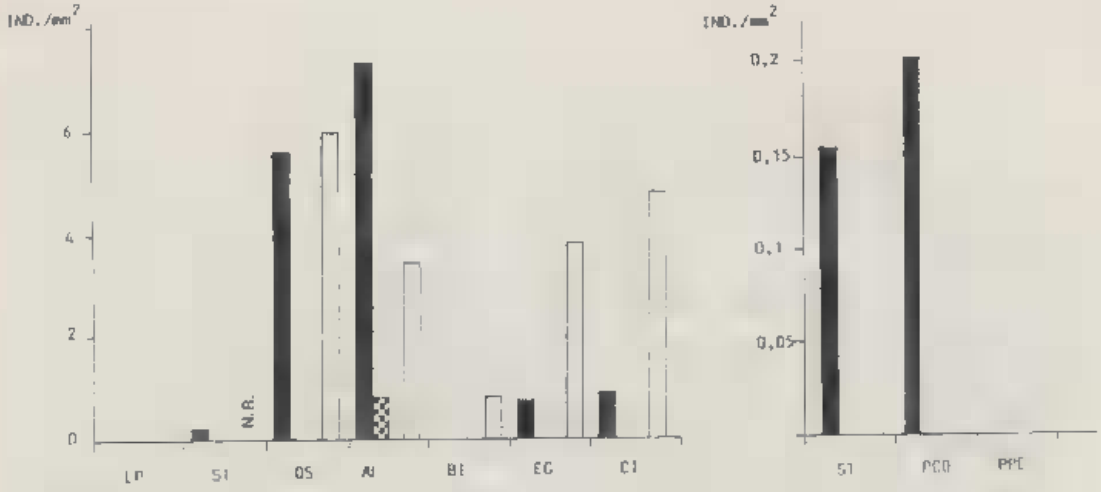

Fig. 2 - Densities of *Chroodactylon ornatum* in 1987/88 on *Stypocaulon* (left) and *Cladophora* (right).
LP: Pointe Revellata; ST: STARESO; OS: Oscelluccia; AL: Alga; BI: Bibliothèque; EG: Egout; CI: Citadelle; PCO: Ferry harbour; PPE: Fishermen's harbour. ■ September 1987; ▨ December 1987; ▩ March 1988; ❑ July 1988. N.R.: not recorded.

Erythrocladia irregularis Rosenvinge (Fig. 3)

Erythrocladia was equally well developed on *Stypocaulon* and *Cladophora*. On *Stypocaulon*, the species was only present in the spring and winter seasons, except at "Egout" where it was recorded in September and "Bibliothèque" where it was present in July at low densities. The highest density observed was 10.7 ind. mm^{-2} at "Egout" in March. On *Cladophora* in the harbours, it was recorded during all sampling periods. In Stareso, the density was rather uniform with a slight peak in September. In the Ferry and Fishermen's harbours, the largest number of individuals was observed in Decembre.

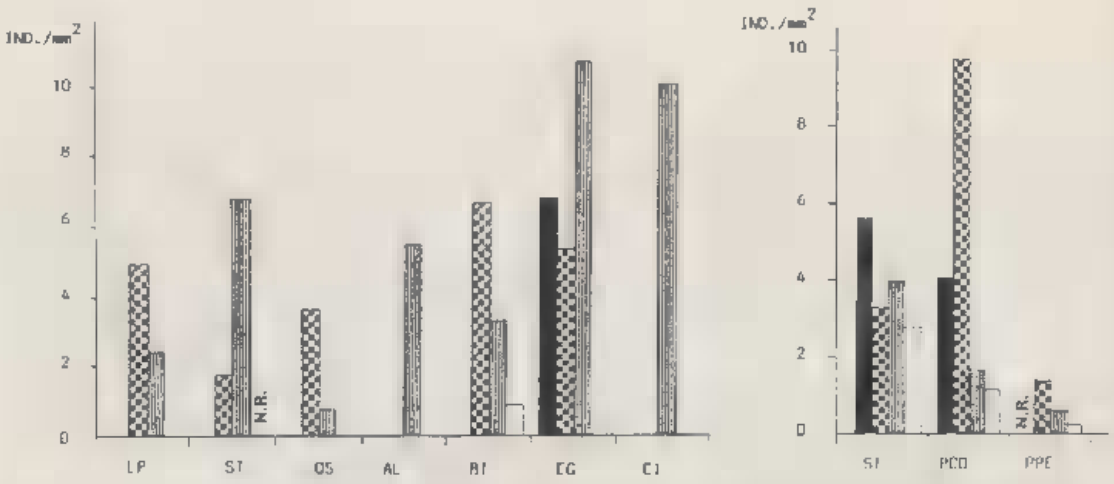

Fig. 3 - Densities of *Erythrocladia irregularis* in 1987/88 on *Stypocaulon* (left) and *Cladophora* (right).

Erytrotrichia carnea (Dillw.) J. Ag. (Fig. 4)

Erythrotrichia carnea was one of the most important epiphytic Bangiophyceae in the Calvi area. On an average, the number of *E. carnea* individuals was larger at "Egout" and the neighbouring stations "Bibliothèque" and "Citadelle" than in the other stations around the bay. On *Stypocaulon*, it was present in all the stations in September with a clear maximum at "Egout" and "Citadelle" where a maximum of 18.2 ind. mm^{-2} was recorded. In December, the lowest density was recorded and the species was absent at "Pointe" and in Stareso; the maximum was observed at "Egout". In March, it was uniformly present in all the stations along the bay. In July, it was absent in most of the stations and was only present at "Bibliothèque", "Egout" and "Citadelle". On *Cladophora* in the harbours, *E. carnea* was only poorly developed in Stareso and the Fishermen's harbour. It was present during all sampling periods in the Ferry harbour where it had its maximum density in spring and in winter.

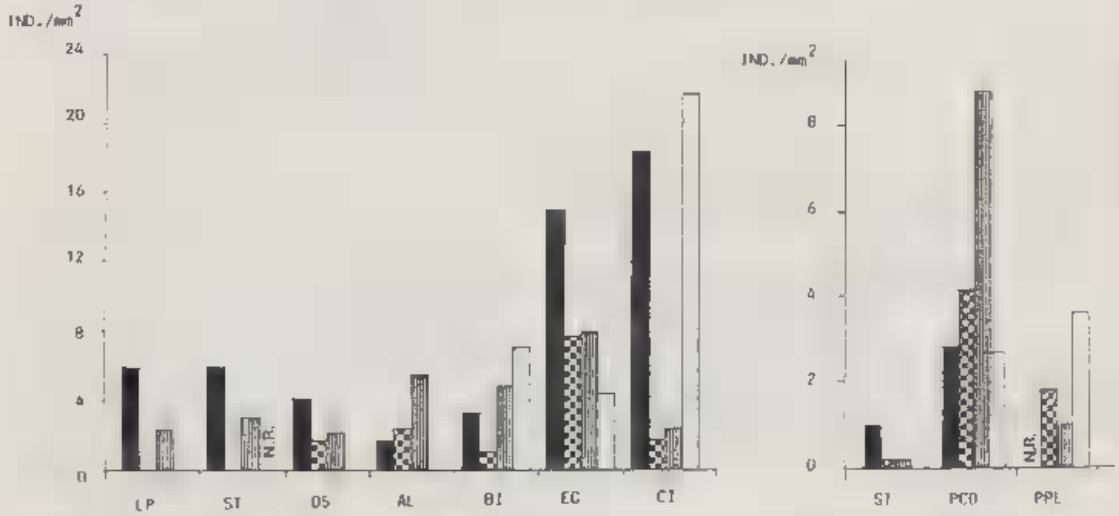

Fig. 4 - Densities of *Erythrotrichia carnea* in 1987/88 on *Stypocaulon* (left) and *Cladophora* (right).

Stylonema alsidii (Zanard.) Drew (Fig. 5)

S. alsidii was better developed on *Stypocaulon* than on *Cladophora* where it is only rarely recorded. On *Stypocaulon*, *S. alsidii* had its maximal development in September, when it was present in all the stations and when the highest density was recorded ("Citadelle": 17.4 ind. mm^{-2}). In December, it was generally less common than in September; the highest densities were recorded at "Egout" and "Citadelle". In March, the population densities of the species were rather uniform along the bay, except at "Alga" where a clear maximum was observed. In July, the species was only present at "Egout" and at he neighbouring stations "Bibliothèque" and "Citadelle", where it had its maximal development. On *Cladophora* in the harbours, it was present in very low numbers in September and March in Stareso; in the Ferry harbour, it was present all the year round with a maximum observed in March. In the Fishermen's harbour the maximum development was recorded in July.

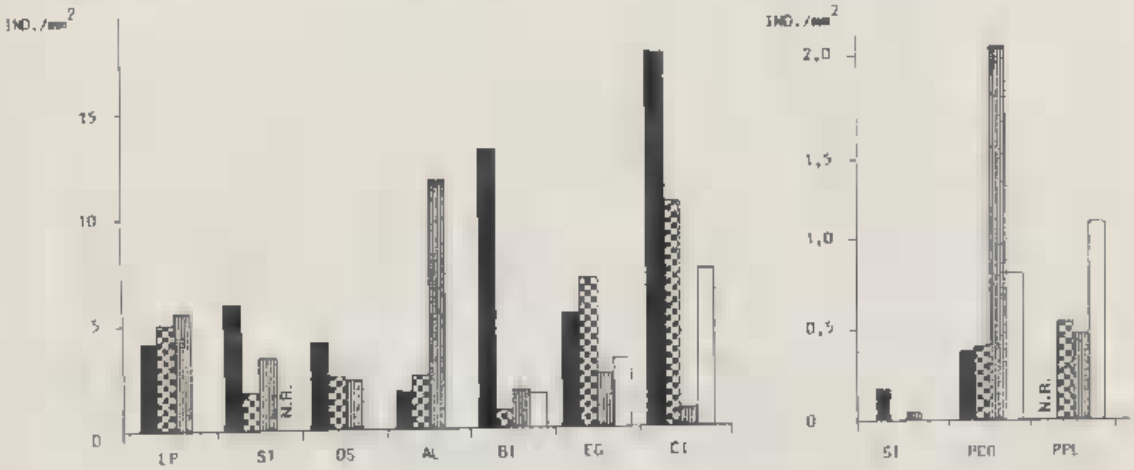

Fig. 5 - Densities of *Stylonema alsidii* in 1987/88 on *Stypocaulon* (left) and *Cladophora* (right).

Stylonema cornu-cervi Reinsch (Fig. 6)

With *Chroodactylon ornatum*, *S. cornu-cervi* was one of the rarest epiphytic Bangiophyceae in the Calvi area; it was especially poorly represented on *Cladophora*. Its optimal development is observed at "Egout" and the neighbouring stations "Bibliothèque" and "Citadelle". On *Stypocaulon* it was present in September only at "Citadelle" and "Egout" where the highest density with 20 ind. mm^{-2} was observed. In December, it was absent at "Pointe" and "Oscelluccia" and the highest densities were observed at "Egout" and "Citadelle". In March, it was not recorded in "Oscelluccia" and "Alga"; the best development was observed at the "Egout" and the neighbouring stations "Bibliothèque" and "Citadelle". In July, the species was only observed at "Egout" and "Bibliothèque". On *Cladophora* in the harbours, it was best represented in September and absent in July in Stareso; in the Ferry harbour, it was present at all sampling periods and had its best development in spring and winter, in the Fishermen's harbour it was only recorded in July.

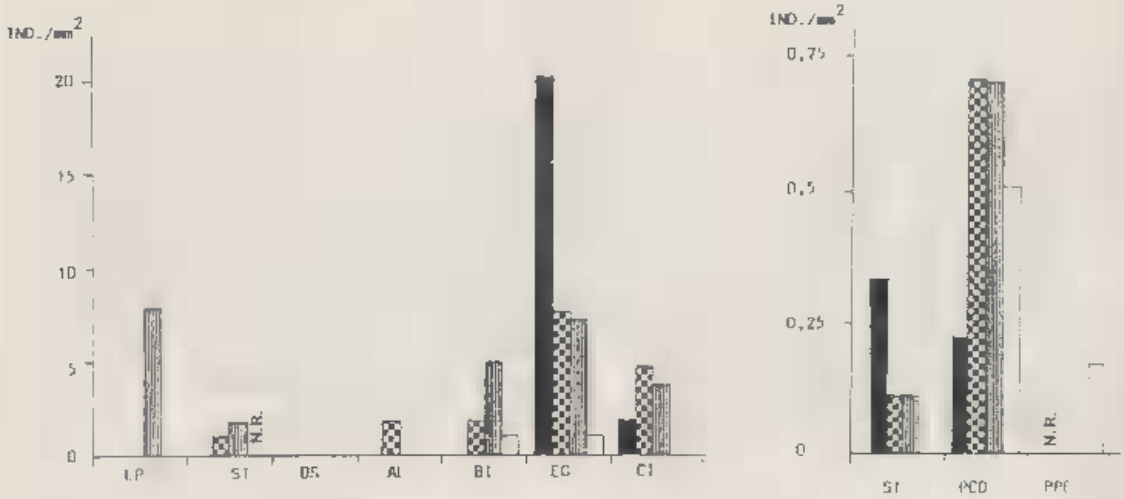

Fig. 6 - Densities of *Stylonema cornu-cervi* in 1987/88 on *Stypocaulon* (left) and *Cladophora* (right).

DISCUSSION

In the Calvi area, *Erythrotrichia carnea*, followed by *Stylonema alsidii* and *Erythrocladia irregularis* are the most important representatives of the epiphytic Bangiophyceae. *Stylonema cornu-cervi* and *Chroodactylon ornatum* are only rarely present in larger amounts.

The populations of epiphytic Bangiophyceae undergo great changes in time and in space in region of Calvi. In spring, due to the upwelling of deep waters and its subsequent mixing, the nutrient concentrations are almost the same all along the bay, furthermore the discharge of sewage is at its minimum. In summer, especially at the end of summer, the nutrients are depleted in the ocean waters except in the stations near to the town of Calvi, particularly near the sewage discharge. Thus two different situations can be distinguished: in spring the stations have similar, high nutrient levels; in summer the non polluted sites nutrients contrast with the polluted sites near "Egout" which receive a continuous imput of nutrients. It was therefore interesting to compare the development of the Bangiophyceae in spring and in summer.

Figs 7 and 8 show the development of the genera *Erythrocladia, Erythrotrichia* and *Stylonema* in March and in September during the two study cycles. To better show the influence of the nutrients on the development of the Bangiophyceae, *Chroodactylon* was not considered for these figures, as the limiting factor for the development of *C. ornatum* seems to be the temperature and not the nutrients.

On *Stypocaulon*, the density of the considered Bangiophyceae was uniform in all the stations in spring 1982 and 1988 (except at "Oscelluccia" with a rather low density in 1988). In September 1981 and 1987, large differences were recorded between the stations and two groups can be distinguished: from the "Pointe" to the "Bibliothèque", the density is low and lower or comparable to the situation observed in spring; at the "Egout" and at the "Citadelle", the density is higher than in the other

stations and is higher than in spring. The density at the "Egout" is about five times the density observed at the "Pointe". This general pattern was particularly pronounced in 1981, but was reproduced in 1987.

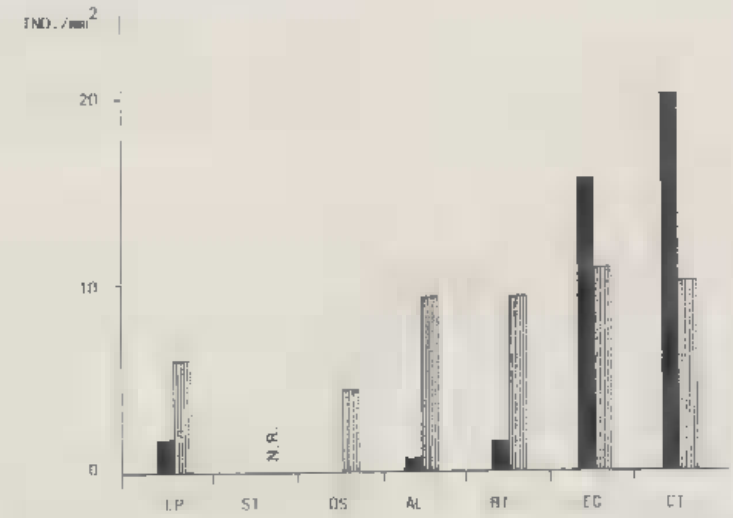

Fig. 7 - Total densities of the Bangiophyceae (-*Chroodactylon*) in September 1981 (■) and March 1982 (▩).

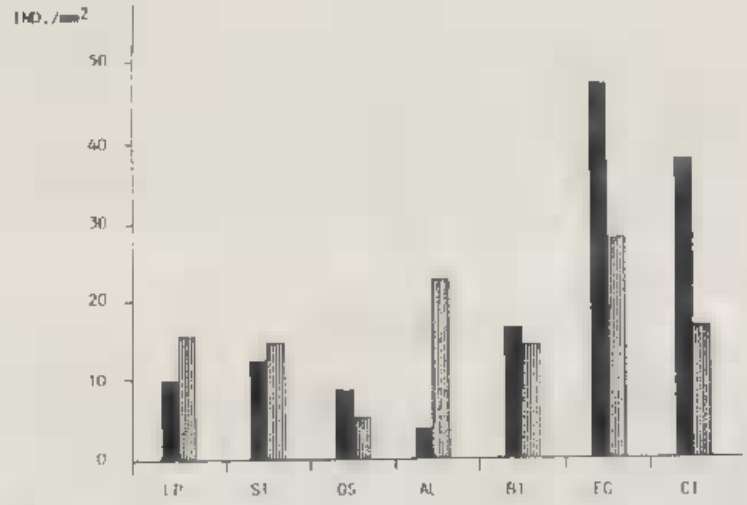

Fig. 8 - Total densities of the Bangiophyceae (-*Chroodactylon*) in September 1987 (■) and March 1988 (▩).

These results indicate that the development of most of the epiphytic Bangiophyceae is favoured by the presence of high nutrient concentrations in the seawater. In summer when the major nutrient are depleted in the surface waters of the open ocean, they only have high densities near the sewage discharge station. These results confirm the observations by Belsher (1974) who showed that the importance of the Bangiophy-

ceae increases when approaching a sewage discharge (Bangiophycean gradient). These microorganisms could thus be used as an indicator group for eutrophication studies.

In comparing Figs. 7 and 8, ▬ increase in the number of Bangiophyceae since 1981, in all the stations except "Oscelluccia" in March, can be observed. The fact that the density of Bangiophyceae is increasing with increasing nutrient supply, the progression of the Bangiophyceae in almost all the stations since 1981 may indicate an increased degree of eutrophication in the bay of Calvi; this development seems to parallel a decrease in the vegetation cover of *Cystoseira* (Hoffmann *et al.*, 1988) in the same area.

The density of Bangiophyceae is generally lower on *Cladophora* than on *Stypocaulon*; this is especially the case for *Stylonema, S. cornu-cervi,* and *Chroodactylon ornatum* which are virtually absent on this green alga. For the development of *Erythrocladia irregularis* and *Erythrotrichia carnea,* no clear trend can be observed. Thus *Erythrocladia irregularis* is almost absent in the Fishermen's harbour, but is well represented in Stareso and the Ferry harbour where it shows a maximal development in December (Fig. 3). On the other hand, *Erythrotrichia* has low densities in the harbours of Stareso and of the Fishermen, whereas it is well represented in the Ferry harbour, especially in spring (Fig. 4). In contrast to the epiphytic Cyanophyceae (Wilmote & Demoulin, 1988), the Bangiophyceae growing on *Cladophora* in the harbours do not permit to reveal any trend.

ACKNOWLEDGEMENTS

Our field work has been performed at Stareso (Oceanographic Field Station of the University of Liège in Calvi, Corsica) and we thank the Director, Dr. D. Bay and the staff for their cooperation. We ▬ also grateful to L. Smeets and J.M. Théate for their help in the underwater collecting, to R. Gago for preparing the illustrations and to R. Fleming for improving the English of the text. L. Hoffmann is senior research associate of the Belgian National Fund for Scientific Research whose support is also acknowledged in the framework of contract F.R.F.C. 245550-80.

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